

**\*\*TITLE\*\***

*ASP Conference Series, Vol. \*\*VOLUME\*\*, \*\*PUBLICATION YEAR\*\**

**\*\*EDITORS\*\***

## The X-ray view of highly obscured AGN

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**Abstract.** The properties of Compton-thick AGN are reviewed, with particular emphasis on BeppoSAX hard X-ray observations. I also discuss evidence for the presence of Compton-thick, circumnuclear matter in unobscured AGN, and I briefly introduce the HELLAS2XMM 5–10 keV survey, discussed in more details in other contributions to this volume.

### 1. Introduction

Both direct (surveys) and indirect (synthesis models of the Cosmic X-ray Background, XRB) methods clearly indicate that most AGN are ‘obscured’ in X-rays, i.e. their emission is seen through absorbing material in excess of the Galactic one. Often (see next section) this absorbing matter is very thick, its column density exceeding the value,  $1.5 \times 10^{-24} \text{ cm}^{-2}$ , for which the Compton scattering optical depth equals unity. For many years it has been customary to identify the absorber with the torus envisaged in popular and, on the whole, very successful Unification Models (Antonucci 1993). We now know that the strictest version of the Unification Models needs modifications, and there are alternative unification models like the outflowing wind proposed by Elvis (2000, and this conference). In the following, I will call ‘torus’ the (sub)pc-scale, large covering factor, Compton-thick circumnuclear matter for which there is plenty of evidence in X-rays (and in other bands), *whatever its actual geometrical configuration*, to be distinguished from dust lanes or other distant (scale of hundreds of parsecs), Compton-thin matter.

I have used the word ‘obscured’, instead of ‘type 2’, deliberately. In the following, I will use ‘type 1’ and ‘type 2’ in their original meaning, which is based on the optical emission line spectrum. As far as X-ray are concerned, I will classify sources as ‘obscured’ and ‘unobscured’, the former including all sources in which there is absorption significantly in excess of the Galactic one. In the classical Unification Models, a one-to-one relation between optical type 1 and unobscured sources, and between type 2 and obscured sources, is predicted. We now know that there is plenty of exceptions (see below and other contributions in this volume): type 1 sources may be obscured in X-rays, and X-ray selected sources may simply not appear as AGN in the optical. Of course, I am not claiming here that there is no relation whatsoever between optical and X-ray appearances. More often than not, the optical (X-ray) appearance is just what one would predict from Unification Models after observing the X-ray (optical) emission. I am only saying that sometimes obscured sources turn out to be type

1 (e.g. Fiore et al. 2001; see also Maiolino, this volume), at one extreme, or dull galaxies (e.g. Mushotzky et al. 2000; Fiore et al. 2000; Barger et al. 2001; Hornschemeier et al. 2001), at the other extreme. On the contrary, I am not aware of any certainly unobscured AGN which are not type 1<sup>1</sup>, and of any type 2 which are not obscured. So, at present the ‘strict’ (in the sense of no exceptions found yet) relations between optical and X-ray classifications are reduced to:

**type 1  $\leftarrow$  unobscured**

**type 2  $\rightarrow$  obscured**

I would not be too much surprised, however, if in the future exceptions to these rules would also be found.

The mismatch between optical and X-ray properties (mismatch from the Unification Models point of view) may solve the long standing problem of the lack, or at least rarity, of type 2 QSO (in fact, at least one convincing case has been presented by Norman et al. 2001), which sometimes is considered a problem for the standard model of the XRB. From X-ray surveys, it is clear that obscured, high luminosity AGN exist, and that is enough for explaining the XRB. The fact that type 2 high luminosity AGN are not found copiously, if not due to some selection effects, may indicate that, for some unclear but certainly worth studying reason, at high luminosity (and/or high redshift) the Narrow Line Regions are invisible or absent altogether. This in turn suggests a luminosity/redshift dependence of the structure of the absorber (as in the obscured Quasar growth model proposed by Fabian 1999). For instance, the absorber may fully cover the nucleus, so either obscuring the NLR or preventing the ionizing photons from illuminating them.

## 2. General properties of X-ray absorbers

X-ray absorption is very common in AGN. All Seyfert 2s observed in X-ray are absorbed, and because Seyfert 2s outnumber Seyfert 1s by a factor of a few, at least in the local Universe, this implies that *optically selected* AGN are preferentially obscured. Synthesis models of the XRB (e.g. Setti & Woltjer 1989; Comastri et al 1995; Comastri et al. 2001; see also Comastri 2001 for a review, and the references therein for the several flavours of the model) also require a large fraction of absorbed sources. Heavy absorption is also very common: about half of the optically selected Seyfert 2s in the local Universe are Compton-thick (e.g. Maiolino et al. 1998). Indeed, the very first object observed by XMM-Newton in the framework of a program devoted to study the absorption properties of optically selected Seyfert 2s, NGC 4968, is clearly a Compton-thick source (Guainazzi et al 2001), as shown in Fig. 1. Actually, there is a relation between optical classification and column density: Risaliti et al. (1999)

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<sup>1</sup>Hardness ratios alone may not be sufficient to indicate obscuration in case of Compton-thick absorbers; with an appropriate choice of the bands, NGC 1068 would appear a very soft source indeed!

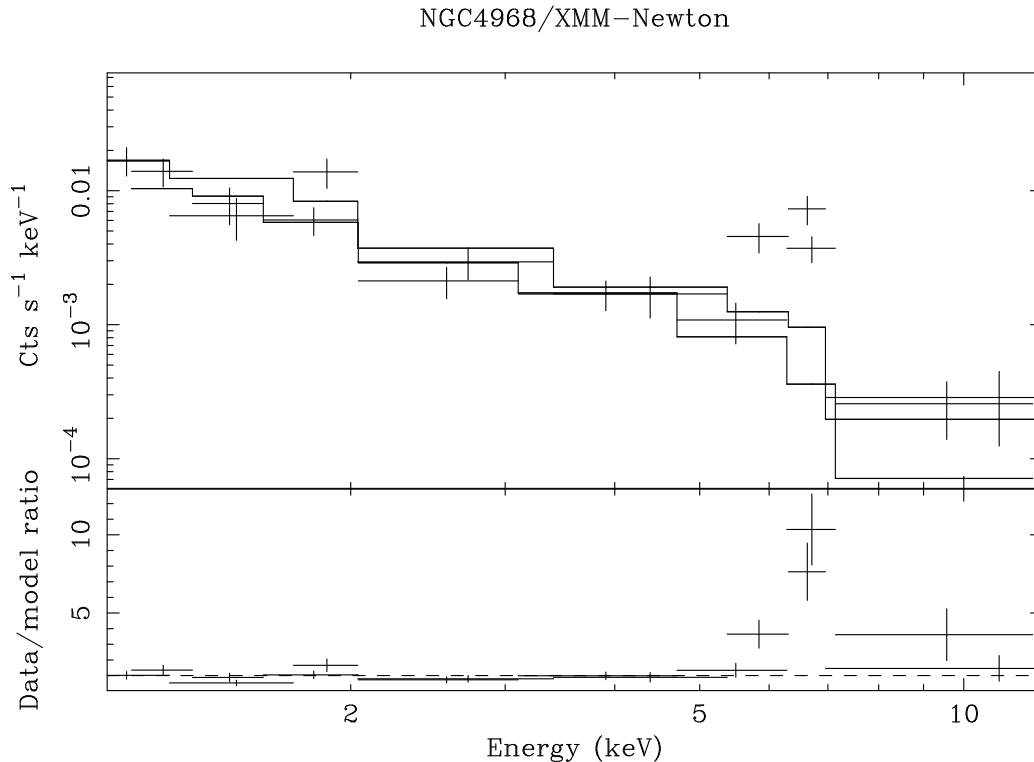


Figure 1. The XMM-*Newton* spectrum of the Seyfert 2 galaxy NGC 4968 (Guainazzi et al. 2001). The spectrum is well fitted by a pure cold reflection component plus a prominent iron line, indicating a Compton-thick source.

have in fact shown that Intermediate (1.8-1.9) Seyferts are usually Compton-thin, while classical Seyfert 2s are Compton-thick. It is possible (Matt 2000) that Compton-thin/Intermediate Seyferts are obscured by the dust lanes at distances of hundred of parsecs which Malkan et al. (1999) found to be common in Seyfert galaxies<sup>2</sup>, while Compton-thick/Seyfert 2s are obscured by the torus (in the abovementioned meaning). The heavy absorbers should have a large covering factor, to account for the large fraction of Compton-thick sources, and must be fairly compact, not to exceed the dynamical mass, at least in the best studied cases like Circinus and NGC 1068 (Risaliti et al. 1999). (For these two sources, a completely independent estimate of the inner size of the torus has been derived by Bianchi et al, 2001 and this volume, by modeling the X-ray line spectra. They found a minimum distance of the torus of about 0.2 and 4 pc, respectively).

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<sup>2</sup>Compton-thin absorption may also be partly due to matter much closer to the Black Hole like the BLR, see Risaliti et al. 2001 for evidence based on variability studies.

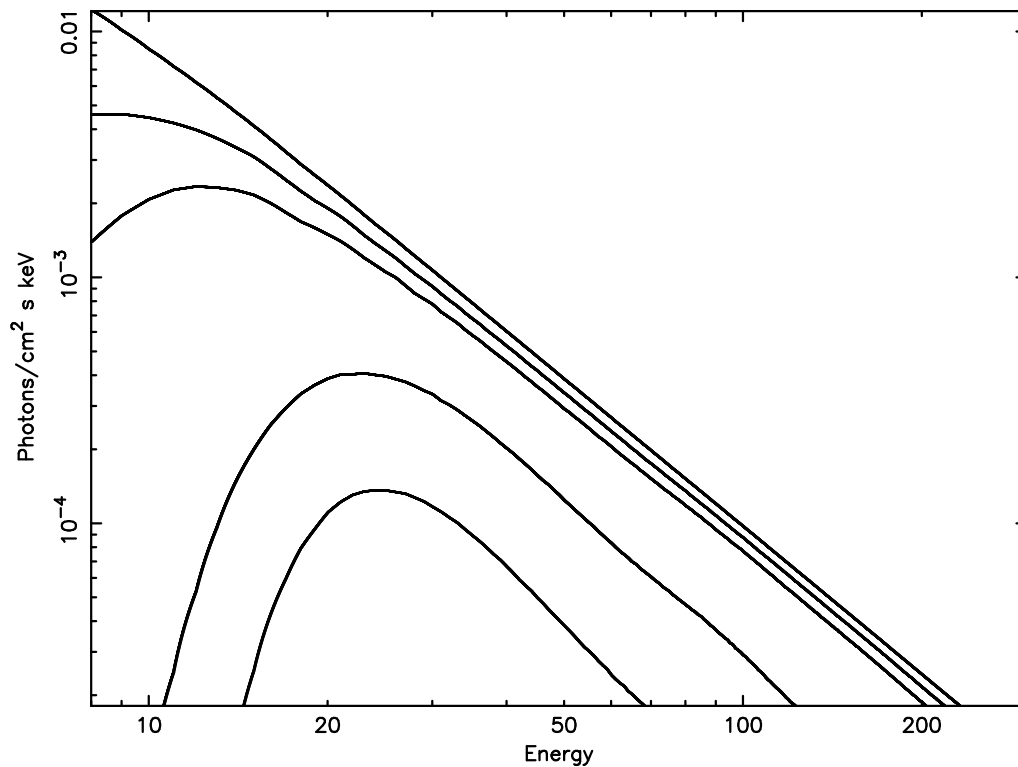


Figure 2. The effect of absorption on the X-ray spectrum of AGN (assumed to be a power law with photon spectral index of 2). Curves are for  $N_H=10^{23}$ ,  $5 \times 10^{23}$ ,  $10^{24}$ ,  $5 \times 10^{24}$  and  $10^{25} \text{ cm}^{-2}$  (from top to bottom). Spectra have been computed following Matt et al. (1999), and include the effects of Compton scattering in a spherical geometry.

### 3. The X-ray spectrum of bright Compton-thick AGN

Just because they are so heavily absorbed, Compton-thick AGN are the ideal sources for studying the circumnuclear matter. The reflection components which, in unabsorbed sources, would be diluted into invisibility by the primary radiation, are here well visible. In these sources absorption is so heavy that no nuclear radiation is observable in the ‘classical’ X-ray band, i.e. below 10 keV. If the column density is of the order of a few times  $10^{24} \text{ cm}^{-2}$ , however, the nucleus may become visible at energies of a few tens of keV (see Fig 2). At these energies, the most sensitive instrument so far has been the PDS onboard BeppoSAX.

In the following subsections I will describe in some details the BeppoSAX results for the brightest of them (for a summary, see Table 1). For other, fainter Compton-thick AGN observed by BeppoSAX see: Malaguti et al. (1998) for NGC 7674; Iwasawa et al. (2001a) for Tololo 0109-383; Franceschini et al. (2000) for IRAS 09104+4109. The data of Mrk 3 are presented by Cappi et al. (1999), while the interesting case of Arp 220 is discussed by Iwasawa et al. (2001b, and

Source	$N_H^a$	CR	WR	$L_X^b$
NGC 1068 <sup>1,2</sup>	$\gtrsim 10$	Y	Y	? ( $> 1$ )
Circinus Galaxy <sup>2,3</sup>	4.3	Y	N (?)	$\sim 0.01$
NGC 6240 <sup>4</sup>	2.2	Y (?)	Y	$\sim 1.2$
Mrk 3 <sup>5</sup>	1.1	Y	Y?	0.9
NGC 7674 <sup>6</sup>	$\gtrsim 10$	Y	N (?)	?
NGC 4945 <sup>7</sup>	2.2	N	N	$\sim 0.03$
TOL 0109-383 <sup>8</sup>	2.0	Y	Y	$\sim 0.2$

Table 1. Summary of the main properties of bright Compton-thick AGN. CR and WR stand for Cold Reflection and Warm (i.e. ionized) Reflection, respectively. Notes: a) in units of  $10^{24} \text{ cm}^{-2}$ ; b) 2–10 keV luminosity in units of  $10^{44} \text{ erg s}^{-1}$ . References: 1) Matt et al. 1997; 2) Guainazzi et al. 1999; 3) Matt et al. 1999; 4) Vignati et al. 1999; 5) Cappi et al. 1999; 6) Malaguti et al. 1998; 7) Guainazzi et al. 2000; 8) Iwasawa et al. 2001a

this volume). For a general discussion of BeppoSAX results on Compton-thick sources see Matt et al. (2000).

### 3.1. NGC 1068

NGC 1068, the archetypal Seyfert 2 and Compton-thick galaxy, has a very complex X-ray morphology, as revealed by *Chandra* observations (Young et al. 2001). The bulk of the iron  $K\alpha$  lines, however, come from the nucleus. ASCA (Ueno et al. 1994; Iwasawa et al. 1997; Netzer & Turner 1997) resolved three iron  $K\alpha$  lines, corresponding to cold, He- and H-like iron. Matt et al. (1996) and Iwasawa et al. (1997) suggested that at least two reflectors were at work, one cold and optically thick (to be identified with the torus), the other hot and optically thin. Matt et al. (1997) confirmed these suggestions by disentangling the two reflecting continua in the BeppoSAX spectrum. No direct emission is observable, suggesting a very thick ( $N_H$  of  $10^{25} \text{ cm}^{-2}$  or more) absorber. A complete analysis of the BeppoSAX data revealed also a O VII line (Guainazzi et al. 1999, now confirmed by *Chandra*, Young et al. 2001, and XMM-*Newton*, Kinkhabwala et al. 2001) which, combined with the lines from intermediate  $Z$  elements like Mg, Si and S, implies that at least a third, warm reflector is present. Bianchi et al. (2001 and this volume) reanalysed the BeppoSAX and ASCA data, and estimated the physical and geometrical properties of the reflectors. In particular, the inner surface of the torus was estimated to be at a distance of  $\sim 4 \text{ pc}$  from the Black Hole.

Comparing the two BeppoSAX observations, performed about 1 year apart, Guainazzi et al. (2000) measured an energy dependent flux variation, explained

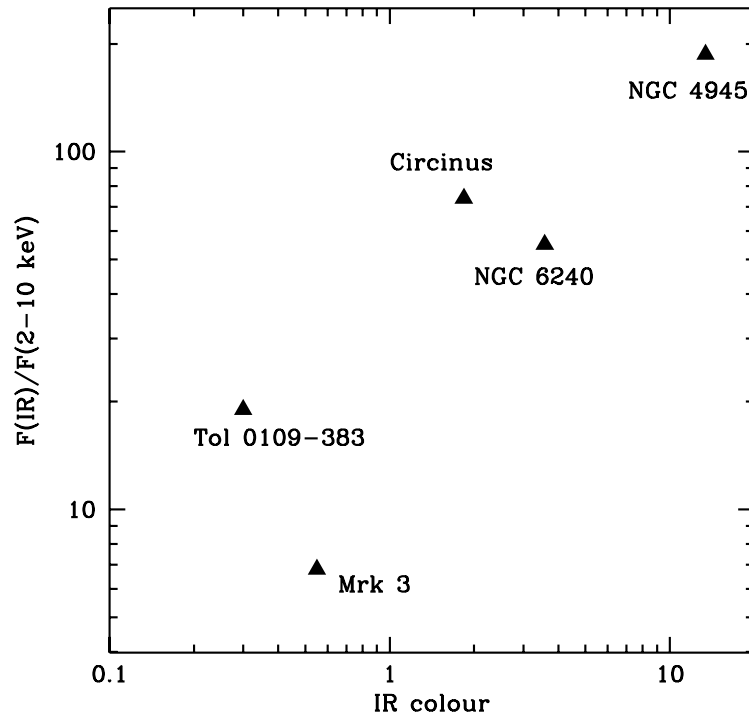


Figure 3. The ratio between the IR and 2–10 keV fluxes (corrected for absorption) vs the IR colour (defined as:  $(S_{60}\nu_{60} + S_{100}\nu_{100})/(S_{12}\nu_{12} + S_{25}\nu_{25})$ ), for the sources in the sample of Matt et al. (2000) for which an estimate of the nuclear X-ray flux is possible.

in terms of a variation of one or both the ionized reflectors. This would imply a size, for these reflectors, of the order of magnitude of a parsec or so.

### 3.2. Circinus Galaxy

Also for the Circinus Galaxy, *Chandra* observations (Sambruna et al. 2001a,b) show a rather complex morphology, but the bulk of the reflection comes from the nuclear region. The spectrum below 10 keV is dominated by a cold reflection component (Matt et al. 1996), while the nuclear radiation becomes visible at energies of a few tens of keV (Matt et al. 1999). An analysis of the ASCA and BeppoSAX line spectrum (Bianchi et al. 2001 and this volume) suggests that the inner surface of the torus is at a distance of about 0.2 pc from the Black Hole.

### 3.3. NGC 6240

Since the discovery by BeppoSAX of the nuclear radiation piercing through a Compton-thick absorber (Vignati et al. 1999), NGC 6240 has become the archetypal obscured, high-luminosity source, and its SED is widely used to study

the relations between IR and X-ray surveys and cosmic backgrounds. From IR diagnostic tools, the source appears to be dominated by starburst emission (Genzel et al. 1998), but already Iwasawa & Comastri (1998) found strong evidence for AGN activity in the ASCA spectrum. This was definitely confirmed by the BeppoSAX observation cited above. The X-ray nuclear luminosity is rather large and, when translated to the bolometric luminosity, suggests that the AGN dominates the energy output in this source. The pretty cold IRAS colours, however (see Fig. 3), point to starburst emission for the far IR. It is likely that in this source starlight and accretion powers are actually of the same order of magnitude. Whether this is just a coincidence, or it is indicating a strong relation between the two phenomena, it is not clear at the moment, but it is certainly a very intriguing question.

Finally, it is worth remembering that from optical spectroscopy NGC 6240 is classified as a LINER (Veilleux et al. 1995), representing one of the first example of the mismatch between optical and X-ray classifications, for which there are now several cases from *Chandra* and XMM-*Newton* surveys.

### 3.4. NGC 4945

An even more extreme case of mismatch between optical and X-ray classifications is that of NGC 4945, for which there is no evidence whatsoever for AGN activity at all wavelengths but in hard X-rays. Iwasawa et al. (1993) discovered a heavily obscured nuclear emission in the *GINGA* spectrum of this source. Later on, Done et al. (1996) confirmed this result with a RXTE observation. Recently, Guainazzi et al. (2000) and Madejski et al. (2000), from BeppoSAX and RXTE observations respectively, discovered large amplitude variations on time scale of thousands of seconds in hard X-rays, where the nuclear radiation dominates the emission. With the column density of the absorber, most of the radiation should emerge after one or more scatterings, if the covering factor of the absorbing matter is large, and no short term variation should be visible, unless the absorber is very close to the nucleus (of the order of milliparsecs or less) or, more likely, the covering factor of the absorber is in this source, differently from the common case, rather small.

## 4. Evidence for the ‘torus’ in unobscured AGN

One of the least tested prediction of Unification Models is that the torus should be present also in type 1/unobscured objects. One of the best way to check it is to search for X-ray reprocessed components (Ghisellini et al. 1994, Krolik et al. 1994). The problem is that reprocessing also occurs in the accretion disc, but fortunately there are at least two significant differences between the two cases: firstly, reprocessed components from the accretion disc should respond to variations of the primary emission on very short time scales (thousands of seconds), while those from the torus should be delayed by months or years, due to the far larger distance from the Black Hole. Secondly, features originating in the innermost part of the accretion disc are strongly affected by GR and kinematic effects, contrary to those from the torus. In this respect, iron line profile is much more useful than the Compton reflection continuum, modifications from the GR

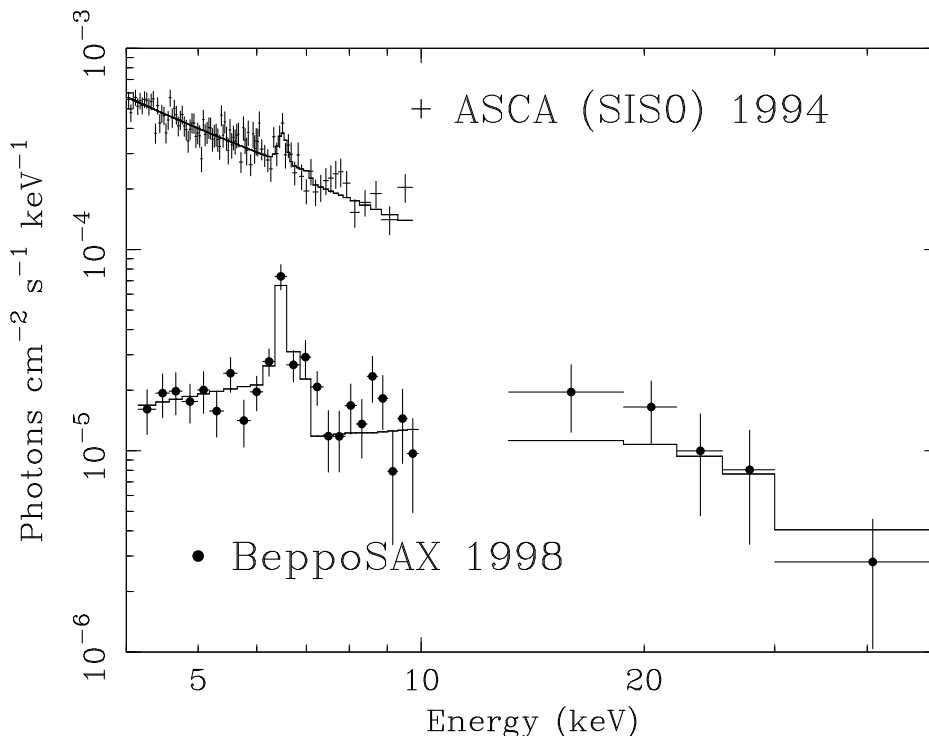


Figure 4. The 1994 ASCA and 1998 BeppoSAX spectra of NGC 4051. During the BeppoSAX observation, only the reflection component was visible. Courtesy of Matteo Guainazzi.

effects being much more dramatic (Fabian et al. 1989; Matt et al. 1991; Fabian et al. 2000 and references therein).

The most convincing case so far for a type 1 AGN with the torus has been obtained by variability studies. In 1998 NGC 4051 went to a prolonged (several months) low state (Uttley et al. 1999), almost at the end of which was observed by BeppoSAX (Guainazzi et al. 1998). From the spectrum, it was clear that the primary emission was disappeared into invisibility, while the reflection components were still there. (This is best seen in comparison with a previous ASCA observation performed during a normal activity state, see Fig. 4). Reprocessing should therefore occurs in matter at a distance of at least a few light-months from the Black Hole. It is worth noting that the reprocessing material must be Compton-thick, to provide a significant reflection continuum.

Observations of the iron line profiles are more ambiguous. *Chandra* gratings and XMM CCDs are discovering several narrow iron lines in Seyfert 1s (e.g. Kaspi et al. 2001; Yaqoob et al. 2001; Reeves et al. 2001; Gondoin et al. 2001; Pounds et al. 2001; see also Lubinski & Zdziarski 2001 for a reanalysis of ASCA data). Without a determination of the amount of associated reflection continuum (hard to achieve with *Chandra* and even with XMM-*Newton*, due to the limited bandwidth) it may be difficult, however, to understand if these narrow



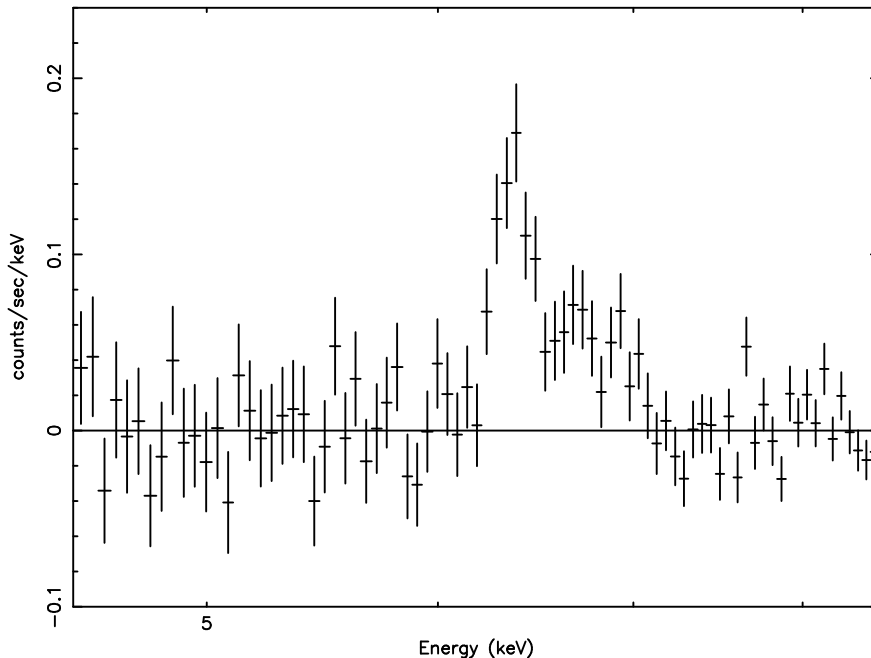


Figure 5. The iron line complex in NGC 5506 from an XMM-*Newton* observation (Matt et al. 2001).

lines come from the torus or from Compton-thin matter, like the Broad Line Region. Even the *Chandra* gratings may not always be sufficient to resolve the line at the velocity of the BLR, often for want of photons rather than of spectral resolution. To overcome these problems, simultaneous observations with hard X-ray instruments have to be performed. We observed NGC 5506 (a Compton-thin obscured AGN, and therefore a source for which there is no direct evidence for the torus) simultaneously with XMM-*Newton* and BeppoSAX (Matt et al. 2001). The iron line, as measured by the EPIC/p-n instrument onboard XMM-*Newton*, is clearly complex, being composed by at least two components: one unresolved and corresponding to neutral matter, the other broad and corresponding to ionized matter (see Fig. 5). Combining the p-n spectrum with the BeppoSAX/PDS one, a strong reflection component is clearly detected. This component clearly comes from neutral matter (as derived from the edge-like feature at 7.1 keV observed in the p-n spectrum) and must therefore be associated with the narrow line. Both components, henceforth, are originated in distant, Compton-thick material.

## 5. Obscured AGN in the Universe

When looking at the Spectral Energy Distribution of the extragalactic Backgrounds, the XRB may appear almost negligible when compared with the sub-mm and IR backgrounds. One can therefore wonder why bothering to perform

X-ray surveys, as they seem to regard a tiny fraction of the energy in the Universe. There are at least two answers to this question. Firstly, the X-ray band is by far the cleanest band where to study accretion luminosity: any point-like source with an X-ray luminosity exceeding  $10^{42}$  erg s<sup>-1</sup> or so is very likely powered by accretion. Secondly, the luminosity we observe in the XRB is only a minority, probably of the order of 10%, of the energy really emitted, the remaining 90% having been absorbed and reemitted at longer wavelengths. For instance, Fabian & Iwasawa (1999) estimated that a by no means negligible fraction (something like 20% or so) of the IR background is actually due to X-ray photons absorbed and reprocessed from the obscuring medium.

Just because most AGN are absorbed (and, moreover, most of the absorbed AGN are Compton-thick), the ideal survey would be at 30 keV (where the XRB peaks!). Unfortunately, at these energies no real imaging instrument is available until the launch of Constellation-X at the end of the decade. In the meanwhile, we are forced to use the hardest imaging instrument available at present.

Prior to the launch of XMM-*Newton*, the MECS instrument onboard BeppoSAX provided the best compromise between hard X-ray sensitivity and spatial resolution. We therefore started a project called HELLAS (High Energy Large Area Survey; Fiore et al. 1999; 2001) aiming to search and identify sources in the 5–10 keV energy range. It is important to note that such a hard selection not only exclude most non AGN X-ray sources, but discovers sources not observable (because heavily obscured) in soft X-ray surveys (a number of HELLAS sources have in fact not been detected by ROSAT, see Vignali et al. 2001). The HELLAS survey has resolved about 25% of the 5–10 keV XRB (Comastri et al. 2001). The sample includes 118 sources, 74 of which have been spectroscopically identified in the optical (La Franca et al. 2001 and this conference). The largest fraction turned out to be type 1 AGN. This is mainly because at these energies, and at these flux limits, unobscured objects still provide the majority of sources. Interestingly, however, some of the objects optically identified as type 1 are indeed obscured in X-rays (Fiore et al. 2001).

The launch of *Chandra* and XMM-*Newton* provided of course a dramatic improvement in X-ray surveys. Many large collaborations are active in this field (see Hasinger, this conference) with the final aim to understand the birth and evolution of Supermassive Black Holes, and their relation with galaxies. We decided to exploit the good sensitivity of XMM-*Newton* up to about 15 keV to continue our project started with BeppoSAX and build up a sample of 5–10 keV XMM-*Newton* selected sources (Baldi et al. 2001 and this conference). We decided to prefer large area to depth, in order to have a sizable sample of relatively bright sources, for which the redshift and optical classification could be easily obtained from 4m class telescopes, and for which at least basic spectral informations can be obtained in X-rays too. First results from this project (named HELLAS2XMM) can be found elsewhere in this volume (see contributions by Baldi and Fiore).

*Acknowledgements* It is a pleasure to thank all my collaborators in these researches: S. Bianchi, A.C. Fabian, F. Fiore, M. Guainazzi, K. Iwasawa, G.C. Perola and all members of the HELLAS team. I thank R. Maiolino, A. Marconi, and M. Salvati for scientific discussions and, of course, for having organized this

conference. I acknowledge financial support from ASI and MURST under grant COFIN-00-02-36.

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